Status of Spacecraft Charging in the USA

Dale C. Ferguson

US Air Force Research Laboratory

Joseph I. Minow

NASA

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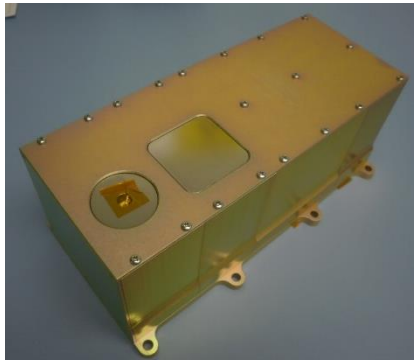
US Spacecraft Charging Activities

- Spacecraft charging continues to be an active and strong area of research, technology development, and operational support in the United States

- Major US contributors to spacecraft charging and related disciplines include personnel from government labs (DOD, DOE, and NASA), private industry, and academia

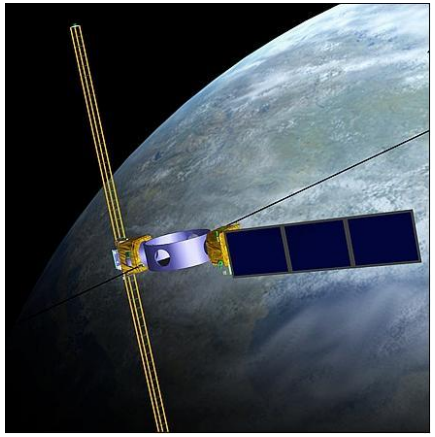
- Major areas of work
  - Flight experiments and on-orbit measurements
  - Ground experiments
  - Environment models
  - Charging analysis tools
  - Operational support and anomaly resolution
  - Electric propulsion
  - Standards

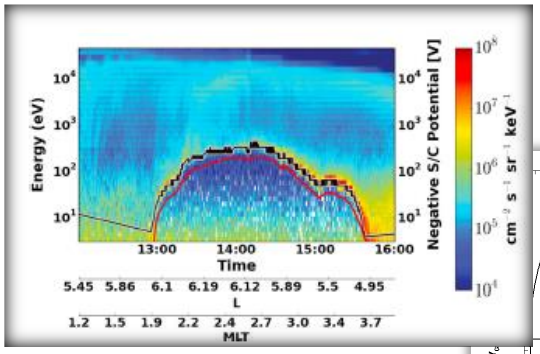
Flight Experiments and On-Orbit Measurements



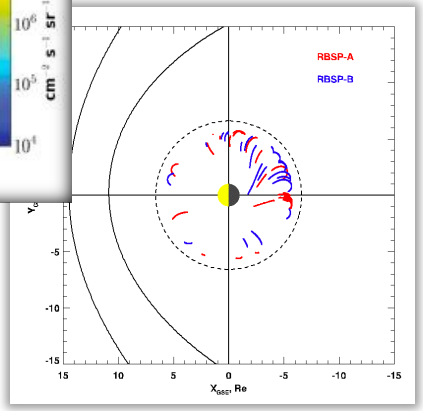
- AFRL CEASE-RR (3U size)
- Compact Environmental Anomaly Sensor
- In the running for the AF Energetic Charged Particle sensor

- Floating Potential Measurement Unit nears 10 years operations on ISS





[Sarno-Smith et al., 2016]

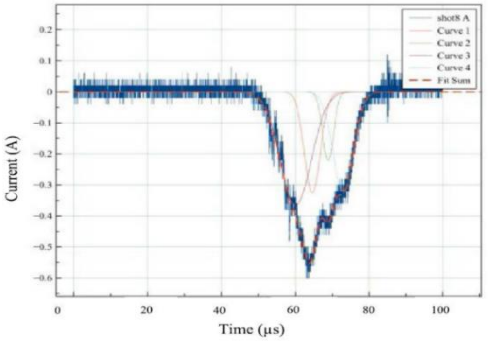


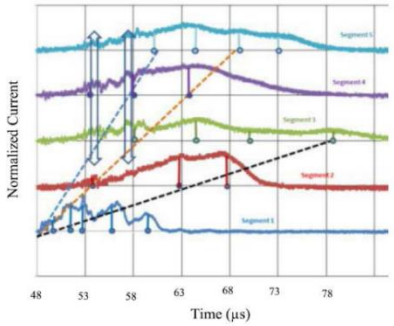
[Parker and Minow, 2014]

- DSX – Demonstration and Science Experiments (AFRL, Lincoln Labs)
- Investigate MEO Wave-Particle Interactions
- Launch in 2017

- NASA's Radiation Belt Storm Probes continues to provide GTO radiation, charging measurements
- 2012 to November 2018 (TBD)

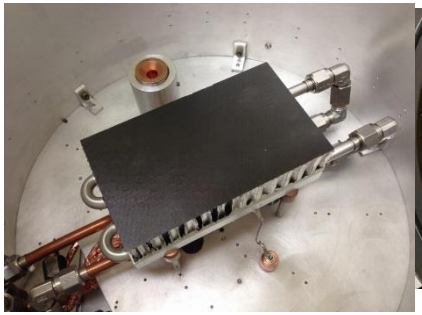
Ground Experiments

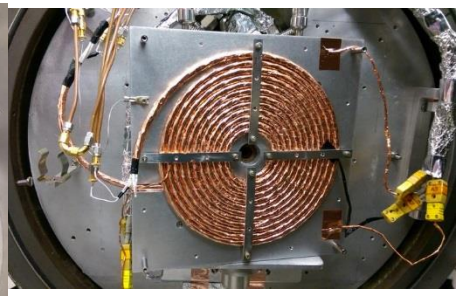




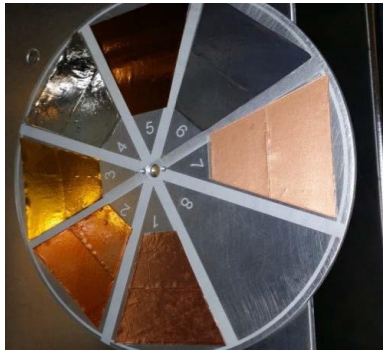
(a) (b)

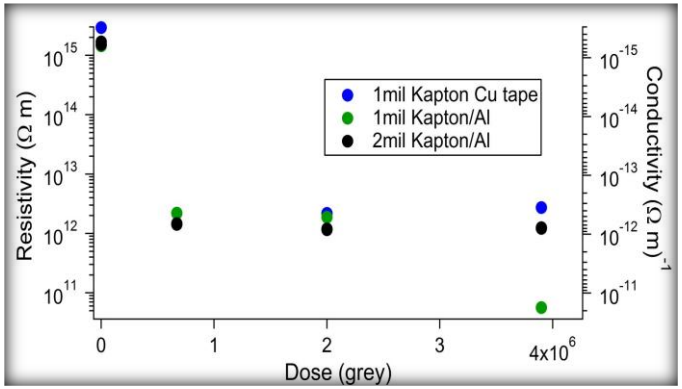
AFRL led plasma expansion speed round robin testing identifies multiple expansion velocities due to components of expanding plasma including carbon, aluminum, and a Kapton fragment



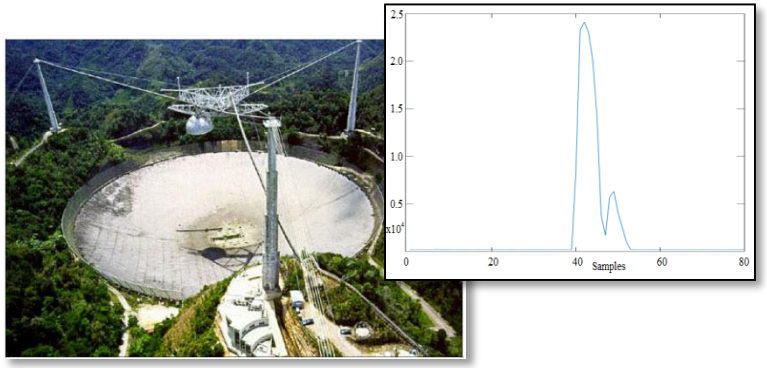


JPL material property and cable arc studies



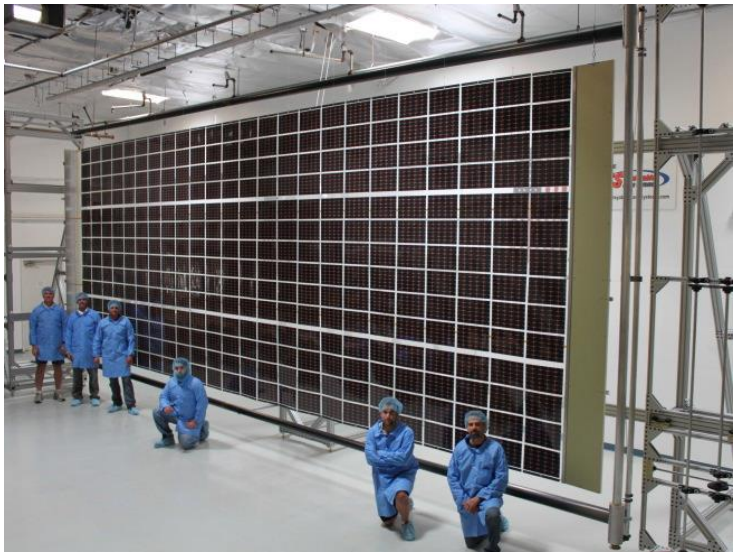


AFRL study of material aging and changes in charging properties (resistivity, secondary electron yield, and photoemission)



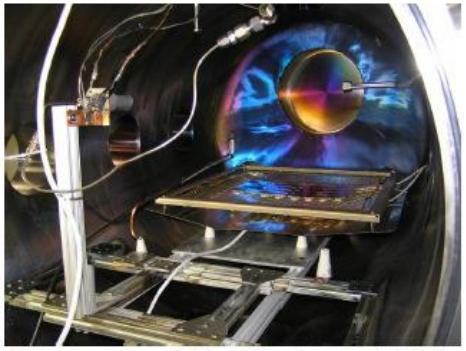
- AFRL attempts to detect GPS arcing from Arecibo
- Large (144 μsec) arc of type possibly responsible for GPS power loss by contaminating arrays

Ground Experiments



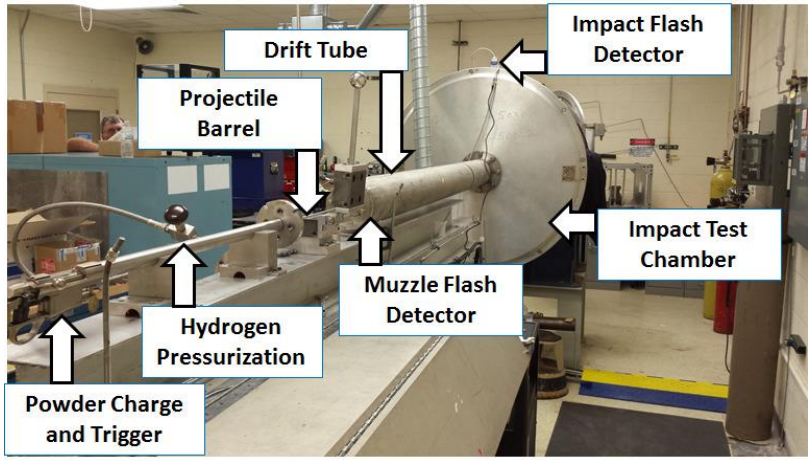
Roll-out Solar Array (Deployable Space Systems)

Test Facility



Plasma source (left) and test region (right) with first test article installed

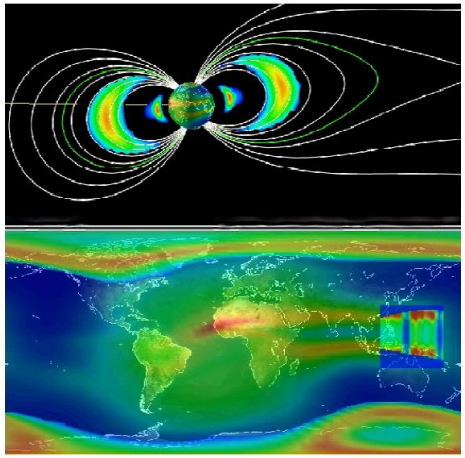
Test Coupon in JPL/Caltech Plasma Test Chamber for High Voltage Solar Arrays



Combined charging and impact testing of solar arrays using the Micro Light Gas Gun at NASA MSFC's Impact Test Facility

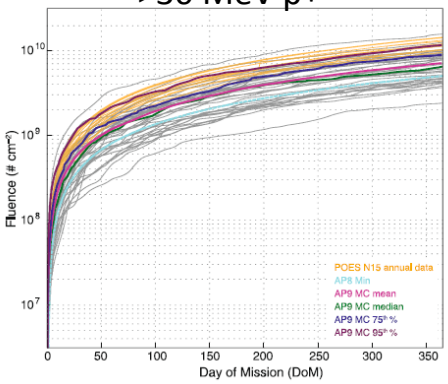
Advanced solar array development and testing by Space Systems Loral, Deployable Space Systems, AFRL, JPL, and MSFC [Hoang et al., 2016]

Environment Models

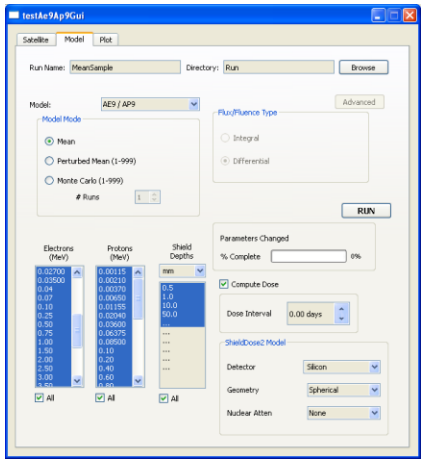


- AF Geospace (AFRL)
- Multiple space environment models with GUI interface

>30 MeV p+

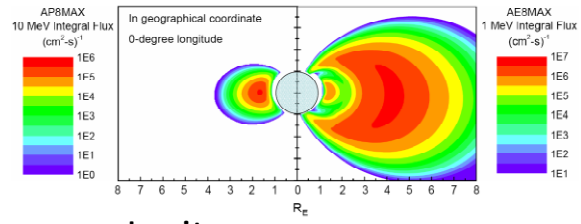


[Ginet et al., 2013]

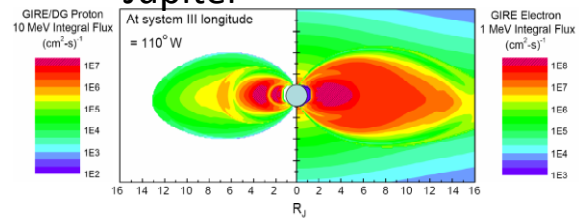


- AE9/AP9/SPM (NRO, Aerospace, AFRL)
- Defacto world standard radiation belt climatology model
- Enabled TACSAT4 discovery of high energy protons filling the slot region

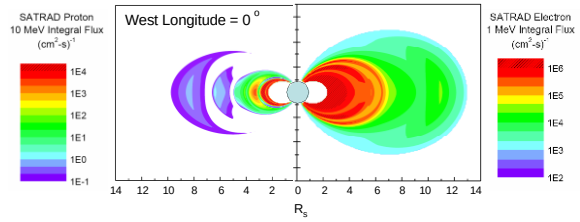
Earth (AE8/AP8)



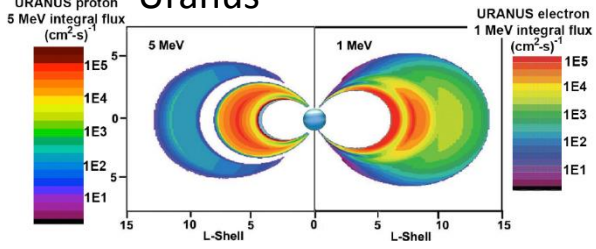
Jupiter



Saturn



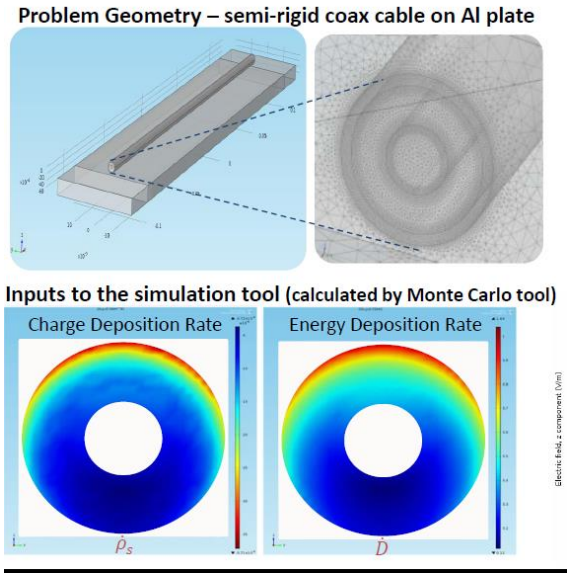
Uranus

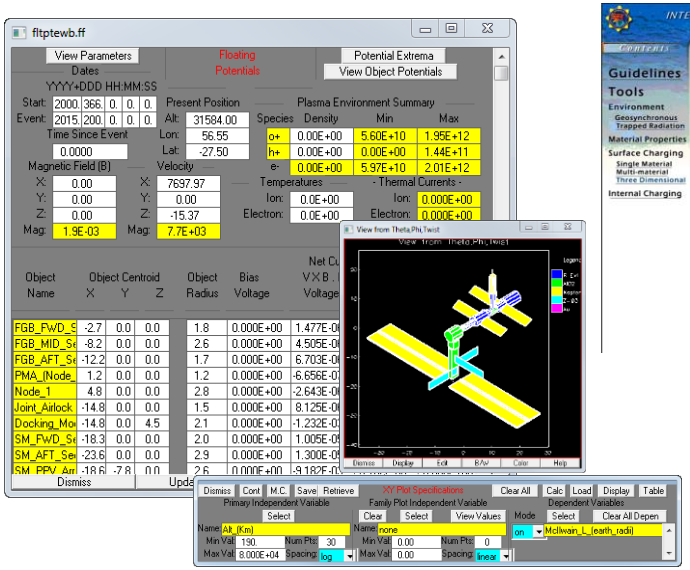


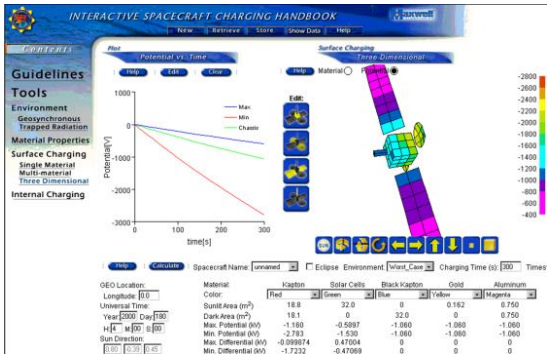
- JPL continues to update and improve radiation belt models for outer planets [Garrett,2016]

Charging Analysis Tools

JPL NUMIT 2D, 3D

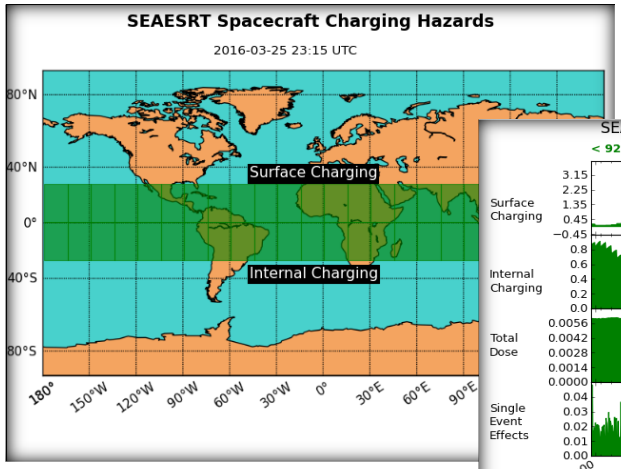




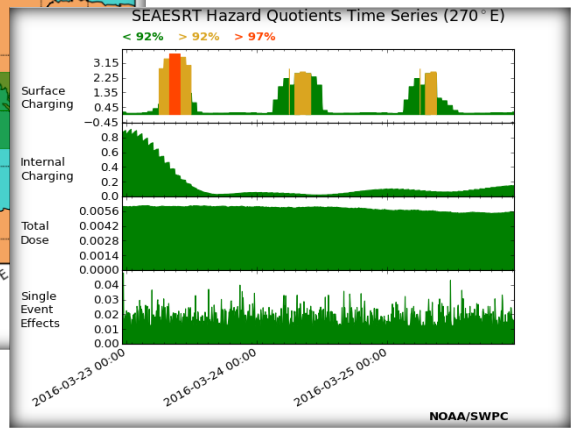


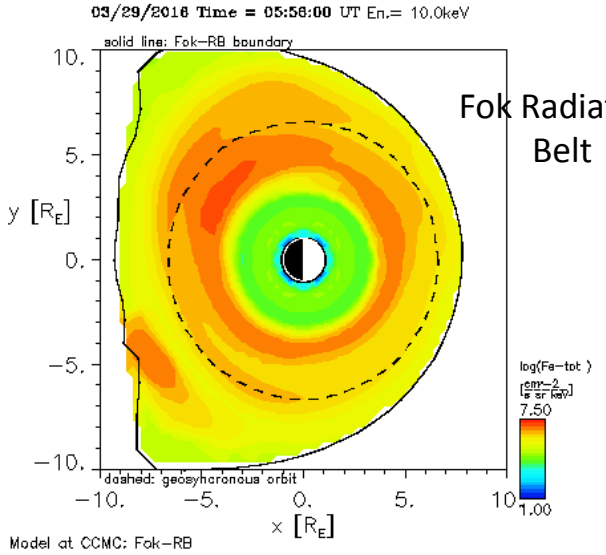
NASCAP Engineering Tool (Leidos)

NASA CCMC Integrated Space Weather Analysis (iSWA) Tools



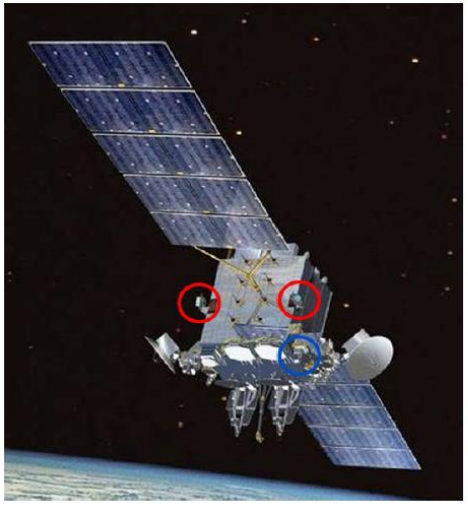
SEAESRT Spacecraft Charging Hazards NOAA SWPC

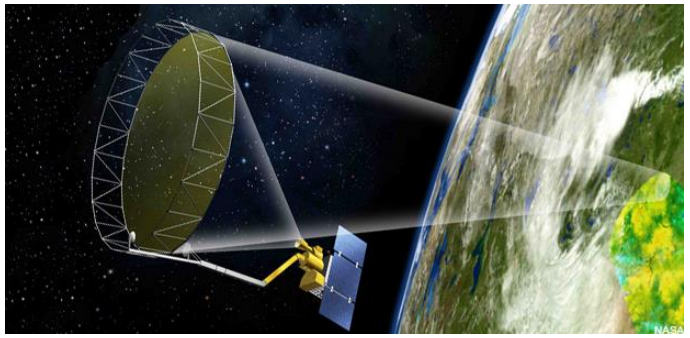




Fok Radiation Belt

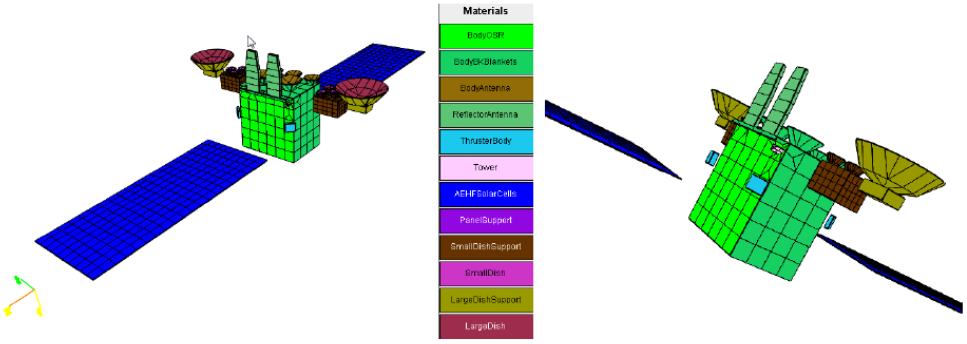
Operational Support and Anomaly Resolution

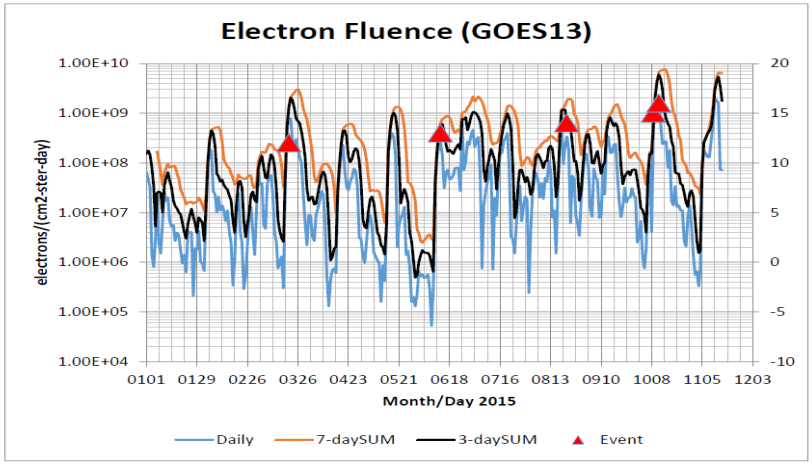




- NASA Soil Microwave Active Passive (SMAP) satellite charging anomaly under investigation by JPL (I. Jun, this conference)

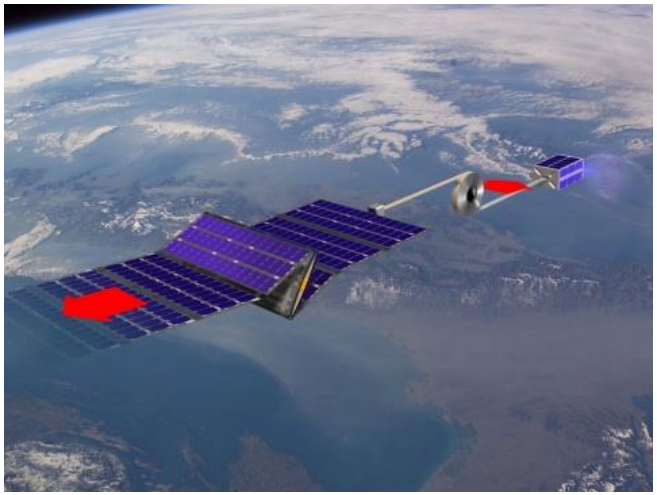
- Nascap modeling in support of thruster degradation on AEHF (Leidos, AFRL)



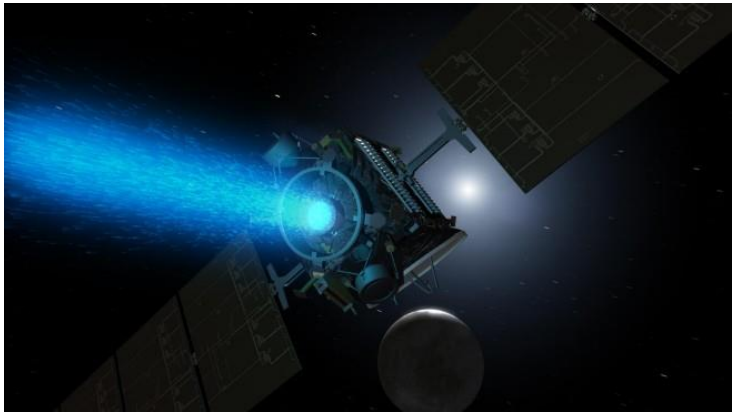


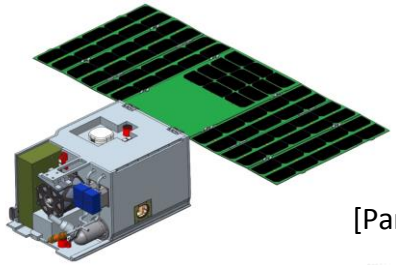
- AF anomaly resolution support for proprietary industry asset
- Best fit to event times – 3 day GOES-13 >2 MeV electron fluences

Electric and Electrodynamic Propulsion

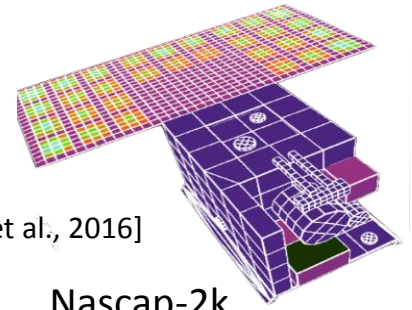


- ElectroDynamic Debris Eliminator (Star, Inc.)
- Electrodynamic tether, a roving, propellantless space vehicle for virtually unlimited delta-V throughout low Earth orbit (LEO)
- Uses vxB.l to generate propulsion, orbit-changing, grappling of debris





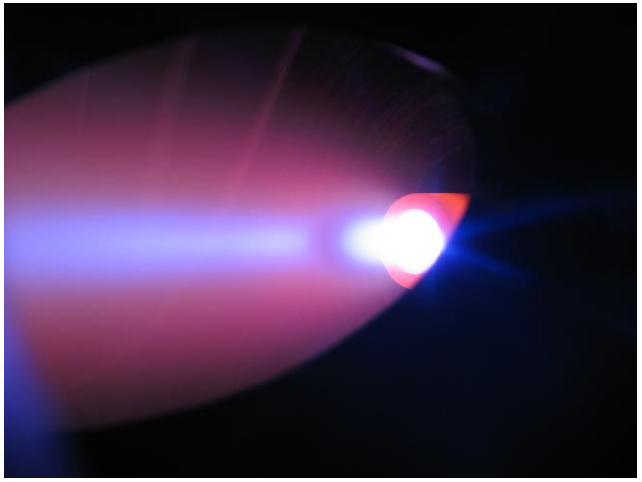
Spacecraft model



[Parker et al., 2016]

Nascap-2k surface potential

- Iodine Satellite (iSAT) is a joint NASA MSFC and GRC electric propulsion technology mission (in development)



- Dawn spacecraft ion propulsion/JPL
- Busek/JPL colloid thrusters on the LISA Pathfinder spacecraft

Standards

NASA-STD-4005A, Low Earth Orbit Spacecraft Charging Design Standard

- High voltage solar array interactions with plasma environment in low Earth orbit
- Updated standard supersedes NASA-STD-4005

NASA-HDBK-4002A, Mitigating In-Space Charging Effects – A Guideline

- Surface and internal charging threat mitigation guideline
- Review and update in progress

ISO CD 19923 -Space environment (natural and artificial)

- Plasma environments for generation of worst case electrical potential differences for spacecraft (AFRL expert, Japan proposal)

ISO N 1100, NWIP Space environment (natural and artificial)

- Spacecraft charging - Earth orbit (AFRL proposed, Japanese, Chinese, Russian experts)